USACERL Technical Report P-91/06
December 1990

US Army Corps
of Engineers
Construction Engineering
Research Laboratory

Framework for Developing an Expert System-Based Decision Support System for Managing U.S. Army Directorates of Engineering and Housing Equipment Fleets

by
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Many U.S. Army installation Directorates of Engineering and Housing, having introduced equipment management systems, now seek to optimize use of the vast amount of information these systems can provide. This report presents outline specifications for a computerized expert system to support fleet management decisions. Included are: (1) an outline of some of the decisions that equipment management systems can help to make, (2) an explanation of the principles of economic analysis that underlie such decisions, (3) a description of the data structures required by an equipment management system, and (4) a description of the kinds of forecasts such a system can generate.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1990	Final

4. TITLE AND SUBTITLE

Framework for Developing an Expert System-Based Decision Support System for Managing U.S. Army Directorates of Engineering and Housing Equipment Fleets

5. FUNDING NUMBERS

PE 4A162731
PR AT41
TA SB
WU CG9

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Construction Engineering Research Laboratory (USACERL)
PO Box 4005
Champaign, IL 61824-4005

8. PERFORMING ORGANIZATION REPORT NUMBER

TR P-91/06

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Engineering and Housing Support Center
ATTN: CEHSC-FB-I
Fort Belvoir, VA 22060-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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Most of the findings of this report are equally applicable to any public works organization. Keywords: Army [illegible], Army [illegible], Inventory analysis, Inventory control, Management information systems. (RWJ)

14. SUBJECT TERMS

expert systems
equipment
Directorate of Engineering and Housing
decision on support systems
management information systems

15. NUMBER OF PAGES

32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), Directorate of Facilities Engineering, under project 4A162731AT41,"Military Facilities Engineering Technology"; Work Unit SB-CG9, "DEH Equipment Maintenance System." The USAEHSC Technical Monitor was Walter Seip, CEHSC-FB-I.

The work was performed by the Facilities Systems Division (FS) of the U.S. Army Construction Engineering Research Laboratory (USACERL). USACERL personnel involved were Robert Neathammer, Team Leader; Donald Hicks, Principal Investigator; and Michael Fuerst, Associate Investigator. Dr. Michael J. O'Connor is the Chief of USACERL-FS. The USACERL technical editor was William J. Wolfe, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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FRAMEWORK FOR DEVELOPING AN EXPERT SYSTEM-BASED DECISION SUPPORT SYSTEM FOR MANAGING U.S. ARMY DIRECTORATES OF ENGINEERING AND HOUSING EQUIPMENT FLEETS

1 INTRODUCTION

Background

U.S. Army Directorate of Engineering and Housing (DEH) equipment managers, Major Commands (MACOMs), and the U.S. Army Corps of Engineers (USACE) find it difficult to evaluate the effectiveness of equipment management, budget effectively for equipment replacement, determine priorities for equipment replacement, or determine necessary fleet size based on workload. Consequently, typical Army practice is to operate equipment well past what field personnel consider useful life. Better equipment management would result in cost savings, decreased personnel requirements, and decreased equipment inventories.

The recent introduction of computerized equipment management systems at several DEH organizations allows collection of extensive data on maintenance and operating histories. However, to use this information to improve management of equipment fleets, the data must be categorized, summarized, and combined with the experience of equipment managers.

Objective

The objectives of this report are to outline the fleet planning decisions that can be supported with data accumulated from computerized equipment management systems, the economic principles which should underlie these decisions, and the manner by which data from the systems can be organized to assist in determining:

1. When to replace or rebuild a given piece of equipment
2. Whether to repair an item that suffers a major breakdown
3. Whether a given piece of equipment should be leased rather than owned
4. How many of an item should be owned to satisfy workload requirements.

A final objective was to propose alternative strategies by which DEHs may charge their customers for equipment use.

Approach

Data from the computerized equipment management systems of Fort Meade, GA, Fort Lee, VA, and Fort Riley, KS, were gathered by phone interview. The economic theories of equipment repair and replacement, and artificial intelligence techniques for data organization were derived from USACERL Draft Technical Report, *A Model for Calculating Cost of Equipment Downtime and Lack of Availability in Directorates of Engineering and Housing.*[1] From these, proposed procedures applicable to DEH equipment fleets were determined.

Mode of Technology Transfer

This report outlines specifications from which computerized fleet management decision procedures at the DEH and MACOM levels can be developed that will be expanded and implemented into an expert system usable by DEH managers and other public works agencies. It is anticipated that a prototype will be available for Army wide testing in FY91, and that the complete automated system will be available through the U.S. Army Engineering and Housing Support Center at Fort Belvoir, VA. Information about the program will be disseminated through the *DEH Digest,* flyers, and Fact Sheets, and funds will be requested from the Facilities Engineering Application Program (FEAP) for demonstrations.

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[1] Michael J. Fuerst, Michael C. Vorster, and Donald K. Hicks, *A Model for Calculating Cost of Equipment Downtime and Lack of Availability in DEH Organizations*, Draft Technical Report (U.S. Army Construction Engineering Research Laboratory [USACERL], December 1989).

2 ECONOMIC CONSIDERATIONS OF FLEET MANAGEMENT DECISIONS

Cost of Owning and Operating Equipment

Fleet management decisions usually require estimation of future owning and operating costs of one current ("incumbent" or "defender") equipment item and one or more proposed alternative ("challenger") equipment items. A defender or challenger may be a single piece, several pieces which work together, or a pool of similar pieces devoted to a certain workload requirement. A rebuilt piece of equipment (or rebuilt incumbent) is considered another challenger. Thus, challengers can represent repair, replace, rebuild, or lease decisions for either individual pieces, or pieces within a fleet. Although much of the discussion which follows will be explained in terms of a single piece of equipment or equipment item, the report will eventually return to the broader scope of "defender" and "challenger."

Future owning and operating costs are forecast from one or more of the following: physical inspection of current equipment, manufacturer's specifications of new or current equipment, and historical operating costs. Ownership costs should be estimated on an item's production unit. For a pickup truck this might be miles (or years if the pickup truck can be expected to be driven the same distance each year), while for a heavy equipment item the unit is typically hours of operation. For some pieces of equipment, a physical measure such as tons of dirt moved is appropriate, although often it is more convenient to use operating hours and to assume some conversion factor to the physical measure. Current record keeping at most locations supports a production unit of hours.

Traditionally considered components of ownership costs are:

1. Operating costs (fuel and lubricants, and heavy equipment operator costs)

2. Preventive maintenance costs

3. Repair costs

4. Capital deterioration (for the Army, this measure is resale value less resale costs, while for nongovernment agencies, depreciation is considered)

5. Taxes and insurance (not applicable to the Army).

Missing from this list is the cost of disrupted operations caused by the equipment item's breakdown during use. Such costs are known as Lack of Availability and Downtime (LAD) costs.[2] These site-specific costs depend on both the tasks for which various pieces of equipment are used and the alternatives available for addressing the impact of the failure. Determining LAD costs is an estimating process which requires the expertise of individuals familiar with local operations.

[2] Michael J. Fuerst, et al.

Four types of LAD costs have been identified:

1. Associated Resource Impact Costs (ARI Costs) occur shortly after a failure, and are directly related to the occurrence of a failure. These costs include the immediate effects on employees' labor costs, such as a driver's lost productive time when a truck breaks down, and the time a mechanic loses from the disrupted work. These costs also include decreased productivity of other machines or personnel, either immediately or after a delay. For example, a truck and its driver lose productivity when a loader fails, and a loader loses productivity when one of the trucks it is loading fails.

2. Lack of Readiness Costs (LOR Costs) are the penalty costs levied when needed equipment is not in a ready condition. For example, a penalty cost will be assessed when a fire truck or other emergency equipment is not available.

3. Service Level Impact Costs (SLI Costs) apply to groups of similar vehicles which form a common pool of resources needed to perform a certain service. These costs result when one or more vehicles in the pool break down and thereby deplete the pool to the extent that the other vehicles must work in a more costly manner to ensure that a specified operational demand is met. An SLI Cost might be the downtime on one of three refuse trucks which causes the other two to work overtime to maintain the required service level.

4. Alternate Method Impact Costs (AMI Costs) occur when the failure and continuing downtime of a given machine forces a change to a less efficient method, thereby increasing costs. Such costs are incurred when a loader and trucks replace a more efficient motor scraper because the scraper is not available, or when standard rather than customized, more efficient vehicles are used to collect refuse. AMI costs usually occur only after an extended period of downtime and frequently involve specific expenditures associated with mobilizing and demobilizing the resources needed for the alternate method.

Equipment items in a specific LAD group working under a given scenario are unlikely to incur LAD costs in all four LAD cost categories. ARI costs are very likely to occur in every instance to reflect, at least, the impact of the failure on the driver or operator. LOR costs are likely to occur if it is accepted that some sort of penalty should be applied when a productive resource is unable to respond to an operational demand whether it is needed or not. Whether SLI or AMI costs occur depends on the characteristics of the LAD group and the scenario under consideration.

Briefly, the procedure for deriving Lack of Availability and Downtime costs requires four steps:

1. Assign to an LAD group each equipment item for which LAD costs from a failure are to be assessed. This group should contain similar (or often identical) equipment items which are typically used for a similar mix of tasks. Sometimes a single item, such as a bulldozer used at a landfill site, is its own LAD group.

2. Describe the work schedules for the tasks performed by the items in each LAD group.

3. Determine the inputs necessary to estimate the applicable LAD costs for a failure under each scenario. Depending on the type of LAD cost, these inputs can include:

- expected length or distribution of the length of the failure
- the delay before the impact of failure is evident

- whether the impact of the failure will terminate or can be alleviated by day's end
- the number of other resources affected by failure
- the change in productivity of these other resources
- the operating cost of the failure on resources.

4. Input for each equipment item, the estimated failures per production unit and the expected duration of each failure, and the number of units of production for each item in a given calendar time.

Time Value of Money and Inflation

Standard economic analysis assumes that a constant dollar's worth of expenditures and income has more weight today than in the future, under the rationale that money in hand can be invested at some return. The use of constant dollars allows the economic analysis to assume a constant buying power. A differential inflation should be applied to cost components not expected to change according to the general rate of inflation. USACERL Technical Report *Economic Analysis: Description and Methods*[3] describes Army-accepted techniques for performing economic an s, including the concepts of Net Present Value (NPV) and Equivalent Uniform Annual Cost (EUAC).

The present value (PV) of any future expenditure (such as operating costs) or income (such as resale value) F_n i.

$$PV = F_n \frac{1}{(1 + i)^n} \quad \text{[Eq 1]}$$

where n = number of time periods into the future in which the expenditure or income occurs
i = the interest rate per time period, known as the discount rate.

For a discount rate of 10 percent, i equals 0.10. Typically, annual operating costs are discounted to the midyear (n = 0.5, 1.5, 2.5, . . .), while salvage or resale value of an item disposed of at year's end are discounted to year's end (n = 1, 2, 3, . . .). The NPV of an alternative equals the sum of the Present Value of the alternative's expenditures and income. When the discount rate equals zero, the NPV equals the algebraic sum of all expenditures and income streams.

The EUAC represents the amount of money (in constant, discounted dollars) which would pay for a project if it were budgeted in equal yearly installments. For a piece of equipment, this is the amount which, if paid annually, will pay for the operation, repair, and capital deterioration of the equipment. The EUAC for a specified time period is calculated as the NPV of disbursements offset by income, divided for that time period by the accumulated discount factor for that time period. The EUAC is a function of the time period, given the formula:

[3] Robert D. Neathammer and Jill D. McLean, *Economic Analysis. Description and Methods*, TR P-89/08 (USACERL, December 1988).

$$EUAC_n = NPV_n \frac{i(1+i)^n}{(1+i)^n - 1.} \qquad \text{[Eq 2]}$$

A subscript n is appended to NPV, because the NPV used for this calculation should include only those expenditures or income actually experienced within the n time periods.

If the discount rate is zero, the EUAC equals the average cost per year, because the NPV becomes the total income stream, and all discount factors are 1.0, meaning that the accumulated discount factor equals the time period length. Thus, in the zero discount rate case:

$$EUAC_n = \frac{\text{Sum of costs/income}}{n} . \qquad \text{[Eq 3]}$$

(Technical Note: The EUAC equation for the nonzero discount rate appears indeterminate when the i approaches 0. However, L'Hospital's rule, found in most calculus texts, allows the evaluation of ostensibly indeterminate limits by differentiating the numerator and denominator before substituting the variables limiting value.)

A computer program for economic analysis must include a cost index for each calendar or fiscal year (past, present, and future) for which data exists in the data base, or which is part of a planning horizon. This allows the analyst to inflate one or more costs as needed. For future years, cost indices are estimated or extracted from officially accepted sources. Labor and fuel escalation rates may differ from the general price increases, dictating separate indices for fuel and labor. In such a case, projected labor costs are derived from past or estimated labor hours, and the fuel costs are derived from past or projected fuel usage. To use price indices correctly, any dollar amount stored in a data base used in an economic analysis for fleet management should be tagged with the date of occurrence, or when a dollar amount represents an accumulation of costs, it should have its individual components weighted so that the sum is expressed in constant dollars for some base year. Unfortunately, data bases for equipment fleet management often contain a value for total parts costs for the item since its acquisition. Although some managers might want to see this actual value, the correct value for economic analysis must be expressed in constant dollars.

The Replacement Decision

Over the life of a piece of equipment, the annual operating costs tend to increase each year (from more repairs and more breakdowns), while the capital costs, or the decrease in resale or salvage price, decrease each year. The EUAC calculated for the first year's ownership is relatively high, but decreases each year as the successive annual losses in resale value decrease. The EUAC bottoms out (usually in 2 to 10 years), and then begins to increase as the increased maintenance cost overtakes the successively smaller decreases in resale value.

When no discount factor is used, the lifetime cumulative discounted cost equals the lifetime cumulative total cost. If an equipment item is to be replaced with an identical item, then the time to replace the item is when the mean annual cost reaches a minimum. In this case, the criteria for replacement with an identical item can be illustrated graphically. Table 1 shows an analysis for an example pickup truck. Figures 1 and 2 graph various cumulative and annual costs from Table 1. Note that the minimum mean annual cost (the correct time for replacement) occurs in year 8, while the minimum annual cost in the any year occurs in year 6. The slope of the line from the origin to any point on the total cost curve in Figure 1 equals the mean annual cost shown in Figure 2. The slope of the total cost curve in Figure 1 is the marginal annual cost (i.e., depreciation plus O&M), shown by the curve with triangles in Figure 2.

When a discount factor is used, a simple geometric analogy does not exist, but an item should be replaced when its EUAC reaches a minimum.

Usually, a nonidentical item ("challenger") is being considered as the replacement (possibly one that is newer or more efficient) for the incumbent (or "defender"). This case considers only the incumbent's projected future costs, since previously incurred costs are not recoverable. First it must be determined when, and at what future value (considering only future costs), the incumbent's EUAC reaches a minimum. Then the minimum EUAC for the challenger is determined. If the challenger's minimum EUAC is less than the incumbent's minimum EUAC, the incumbent should be replaced. This comparative EUAC does not require that the minimum EUAC for the alternative occurs in the same future year. In this analysis, the incumbent's disposal costs should be added and the incumbent's salvage price should be subtracted from the challenger's acquisition cost. Disposal costs and salvage value are incurred only if the replacement actually occurs, and should not be considered a valid component of the incumbent's annual cost. If the incumbent is to be kept, its disposal costs and salvage value are considered in the year that its EUAC is at a minimum.

Due to the relatively high initial investment for replacement equipment, replacement analysis that does not consider productivity differences and LAD often recommends repeated repair of equipment which operating personnel consider obsolete, inefficient, or which "spends more time in the shop than not." Productivity differences and LAD costs are not measured per budget year, but per unit of equipment usage, such as unit miles or hours. Since the timing and volume of many of an item's repairs are usage based, implicit in this discussion is an expected usage per year. Economic and budgetary decisions are made according to the budgetary cycle, also a year. To reconcile the two methods of analysis, the alternative of any replacement analysis must be compared assuming identical units of production in each year. For example, if a new item can complete more of a task per unit of usage than the current equipment, and if the workload is expected to increase, then the analysis must consider the new item performing the new workload versus the old item supplemented by an overtime or equipment leasing to perform the new workload.

Table 1

Analysis for Example Pickup Truck

(1) Original Purchase Price	(2) Salvage Value	(3) Annual Depre-ciation	(4) Cumula-tive Depre-ciation (1)-(2)	(5) Annual Operating	(6) Annual Maint.	(7) Annual Down-time	(8) Annual O&M (5)+(6)+(7)	(9) Cumulative O&M	(10) Annual Total Cost (3)+(8)	(11) Cumula-tive Total Cost	(12) Year	(13) Mean Annual Costs (11)/(12)
16500	10627	5873	5873	2000	1000	200	3200	3200	9073	9073	1	9073
16500	6834	3743	9616	2050	1200	700	3950	7150	7693	16766	2	8383
16500	4409	2475	12091	2100	1200	800	4100	11250	6575	23341	3	7780
16500	2839	1570	13661	2150	1600	1000	4750	16000	6320	29661	4	7415
16500	1828	1011	14672	2200	1700	1100	5000	21000	6011	35672	5	7134
16500	1177	651	15323	2250	1900	1100	5250	26250	5901	41573	6	6929
16500	758	419	15742	2300	2100	1400	5800	32050	6219	47792	7	6827
16500	488	270	16012	2350	2200	1800	6350	38400	6620	54412	8	6802
16500	315	173	16185	2400	3400	2000	7800	46200	7973	62385	9	6932
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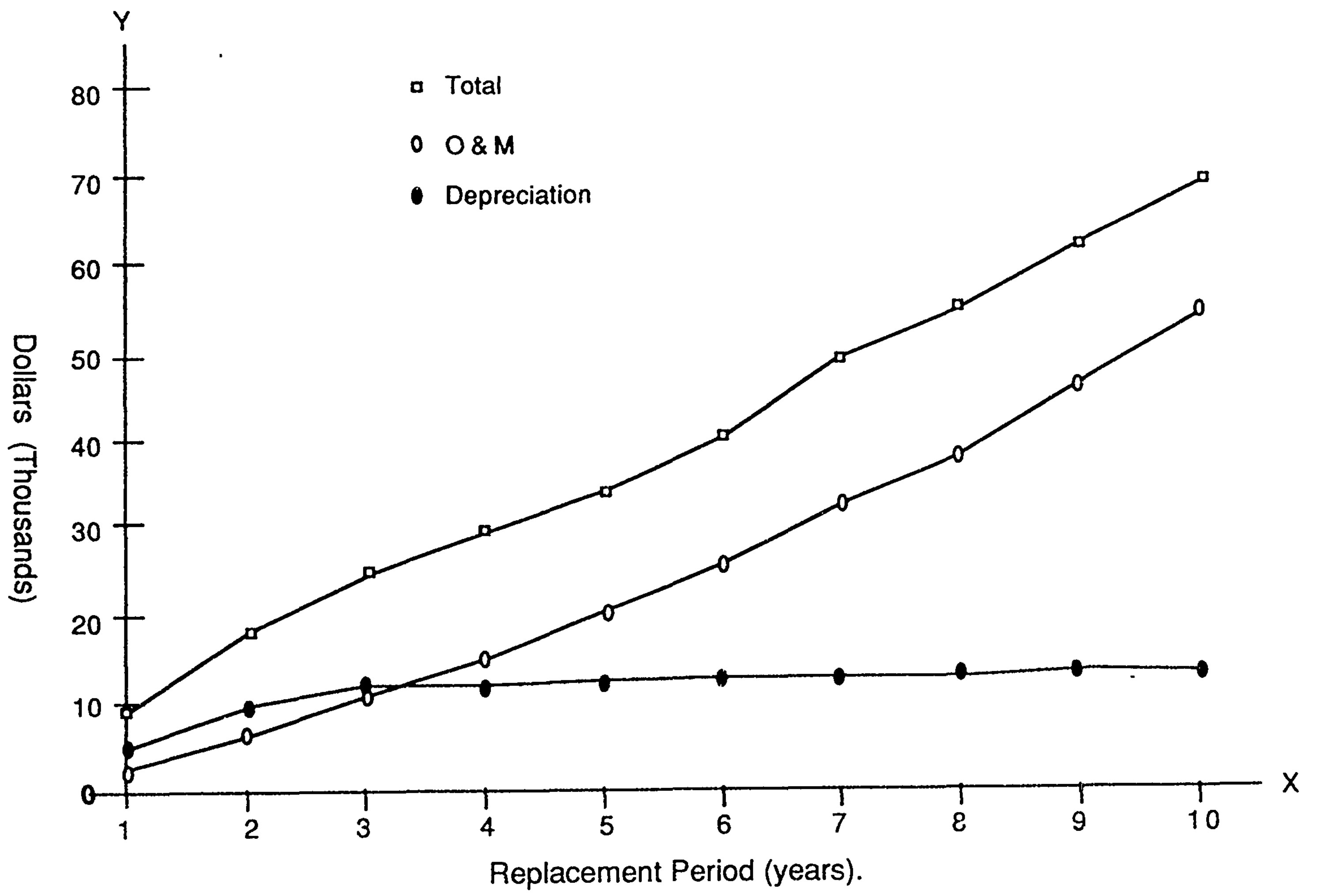

Figure 1. Cumulative costs for example pickup truck.

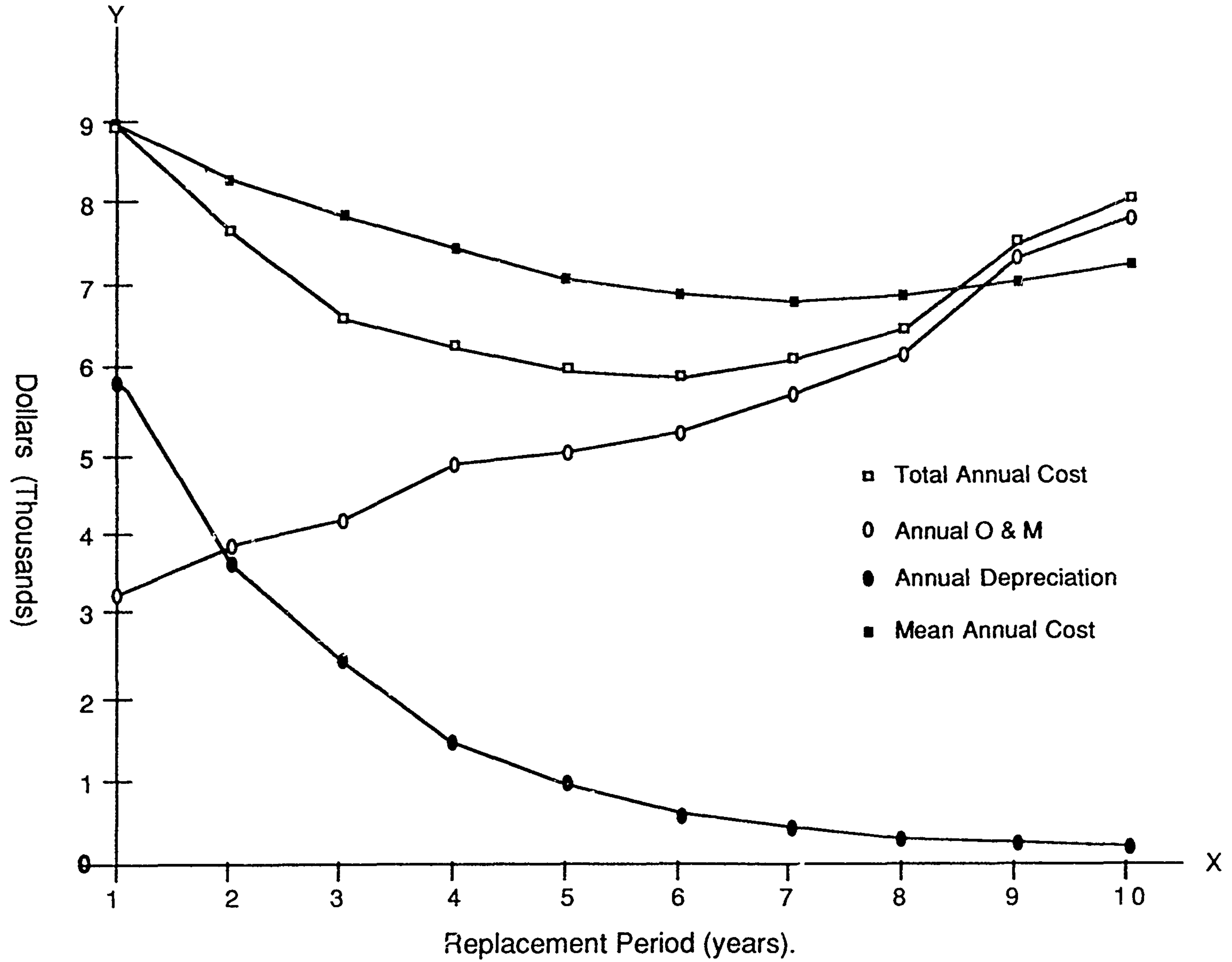

Figure 2. Annual costs for example pickup trucks.

The Repair or Rebuild Decision

If a needed repair or rebuild was anticipated in any recent decision to retain the equipment, then the repair or rebuild should be made, unless additional alternatives become available. If misuse or an accident caused the requirement, the maintenance repair is not relevant; only the replace decision analysis is required. Any LAD type costs associated with delays in effecting these three alternatives must also be considered.

Rebuild alternatives must account for the expected productivity of the rebuilt machine, which may differ from the existing or new one.

The Own or Lease Decision

The own or lease decision applies to two different situations. The first is to continue owning an item already possessed, as opposed to disposing of it and leasing an equivalent item. Declining usage for the possessed item might motivate considering such a decision. Comparing these alternatives is valid only if no item is owned at the end of the lease period. Thus, the retain option should terminate with the expected resale proceeds of the incumbent item at the end of the proposed analysis period as cash proceeds, while the lease option realizes the initial resale of the incumbent as cash proceeds. Several retention periods for the incumbent, and several lease periods might be compared in such an analysis, depending on the circumstances. Since EUAC is the preferred economic measure, the lease period need not equal the retention period, although it often will. The second situation involves deciding whether to buy or lease an item for a new work requirement. Here, the item (if purchased), must realize its resale value at the end of the ownership or lease period.

Alternatives for Charging for Equipment Use

Currently, the Army does not charge DEH shops or DEH projects for DEH-related equipment. DEH shops are not charged for daily use of truck, or for use of DEH equipment. Although some use of equipment is recorded against projects, no funds are transferred from a project fund to a DEH equipment fund.

The issues are how and whether to charge DEH customers for operating expenses and the replacement costs of equipment (i.e., capital losses of equipment). Charging users for operating costs requires reallocating DEH funds directly to DEH shops, and increasing project budgets. Equipment management computer programs that can derive the amounts to charge can calculate costs within an installation.

Charging DEH customers for capital replacement is more difficult, since major equipment purchases do not come from local funds. (Major equipment purchases are usually funded by Army or MACOM funds, although purchases of limited amounts can be made locally.) Making such charges would require the Army budget for DEH equipment to be allocated to installations, and would require certain policy decisions. Among policy issues are the extent to which Army-wide equipment purchase funds would be transferred to installations, the extent to which installations would fund their own major purchases, and how to resolve initial inequities due to the current status of an installation's equipment fleet. The Department of the Army (DA) and MACOMs must continue to be a source for guidance, advice, and coordination of large buys.

3 CAPITAL BUDGETING AND TIME-STAGED DECISIONS

Important interactions exist among items of the DEH fleet. Several DEH equipment managers have reported that they could meet their needs with a smaller inventory of more reliable equipment. One equipment manager felt he could function with nine reliable dump trucks rather than the 14 outdated ones he now has.

Considering the items' interaction, DEH equipment can be classified as follows:

1. One or a pool of items which performs a service at a continuous workload level for the installation—If an item fails during use, either an available spare is used, the remaining items work overtime to cover the slack, the installation does without, or, in case of emergency, an alternate method is used. Examples of such items include garbage trucks (used year round) or lawn tractors (used in spring and summer), or a specially equipped bulldozer covering refuse at a landfill site. If the individual items in such a pool vary significantly in age, the policy probably exists to use the older, less reliable items only if needed. Replacing the oldest item affects the unique service provided in at least two ways:

- The usage rates of the remaining items decrease because the new item may be more reliable, faster, and/or more fuel efficient. Thus, within a pool of items, usage rates and operating costs depend upon repair-replace decisions of the individual items.

- The maintenance hours required for the fleet will decrease.

Thus, any alternative involving the replacement or rebuild of a member of this group requires an analysis, possibly by simulation, of the resulting costs of the pool providing the service. Such simulations require, for each member and potential member, estimates of breakdowns per unit of productivity, and the hours (or some representation of the hours) required for repair. The time required for repair should include both delays (due to the unavailability of mechanics, parts, or bays) and actual mechanic hours. Such simulations can also assess LAD costs for specific members of the pool. The level of service provided can affect the analysis. For example, lawns may be mowed weekly or every 10 days, and refuse may get collected once or twice weekly. Such simulations can also be used to analyze the effects of limiting delay times in making repairs.

2. One or a pool of items of similar nature performing one or more tasks, at an intermittent workload—Examples are a fleet of dump trucks, where between one and five items might be in use at a given time; and a "cherry picker," used for changing street lights and tree trimming. Each typical task assigned to pool members is a scenario for LAD determination. Most of the above observations for the continuous level of service group apply, except that simulation of the operation of this type of group requires knowledge of the types, lengths, and priorities of work requests to the group. Priorities are important if some tasks can be deferred or interrupted until more pressing tasks have been completed. A goal in managing this type of pool, instead of or in addition to minimizing the cost to perform the pool's workload, could be to limit the number of times that critical tasks are delayed due to lack of an idle or reassignable member of the pool. The number of times may be a percentage or number per month of requests which cannot be immediately satisfied.

For pools with only one or two items, or pools which perform intermittent and/or noncritical tasks, each pool member can be considered independently, and estimates rather than simulations of usage will be adequate to compute the operating and maintenance costs for competing alternatives.

The various decisions discussed in Chapter 2 require projections of the number of defender and challenger production units in a pool of equipment items. To budget a pool of items requires either projecting the pool's annual workload over several years or establishing the criterion for the desired level of service. Often one projection can be used for several future years. Simulating the performance or reconfiguration of a pool requires a simulation over each future year, because each year the members of a pool deteriorate and require more maintenance.

One way to project the effects of alternatives over several years is to consider time-staged alternatives for upgrading the fleet. For example, if two dump trucks are to be procured, both could be acquired this year, or both next year, or one this year and one next year.

Replacing one or more of the oldest members of a pool may allow pool size to decrease. If the sale or disposal of the excess members becomes part of the alternative, the resulting proceeds or costs are incorporated into the EUAC calculation.

Ideally, a pool should consist of identical items, all of which were acquired and retired at the same time. Each item would have experienced approximately the same usage while owned. However, most public agencies cannot afford to convert to such pools. Even if they did, accidents or equipment abuse would intervene. A pool must compete against the equipment requests of other requirements.

Every alternative implies: (1) a unique set of utilizations and costs for each pool member and, therefore, for the whole pool, (2) a load on the organization's maintenance capabilities (budget or, more likely, staffing), and (3) a load on the capital and operating budgets of current and future years. Usage requirements, expected maintenance levels, and budget limitations can be expressed as linear constraints. Therefore, linear optimization models, available through several computer codes, can be used to select the decisions which will minimize fleet operation costs. Constraints for such a model could include quarterly or annual capital operating budget constraints, quarterly maintenance personnel constraints by quarter and/or skill, charges for using outside maintenance services, and carryover of constraint violations to successive time periods.

4 DATA STRUCTURES AND DATA TO SUPPORT FLEET MANAGEMENT DECISIONS

DBMS and Frames as Descriptions of an Equipment Fleet

Equipment maintenance and management computer programs currently available use data base management systems (DBMS), which define "entities" and "attributes" for each type of entity. Each "instance," or occurrence of an entity, has its own set of attribute "values." A programming language accesses the various entities and attributes, and ensures that all updates and changes maintain consistency among the various entity instances and attribute values.

For certain types of applications, DBMS are very effective, but for others they are of limited use. For example, in many DBMS-based applications, repetitive data for similar but not identical entities must often be entered. For equipment management systems, data descriptive of a vehicle (such as transmission and engine type for a Ford pickup truck), may have to be reentered for each instance of the vehicle. Values of certain attributes which are derived from attributes in the same or other entities must be explicitly calculated by the programming language when needed, and the programmer must remember to call appropriate routines to do so. These limitations can be minimized by good programming practices, but often result in complicated codes.

A frame is a generalization of entities. Frames have "slots," rather than attributes. A slot is: (1) a data item, such as an attribute value, (2) a procedure or routine which calculates a value automatically when the value is needed, or (3) a reference to another frame.

A slot may have: (1) rules associated with it to define its permissible values, (2) procedures followed when its values are accessed, such as updating a value if necessary, and (3) procedures followed when its values are updated.

A frame's slots can be assigned default values which are automatically inherited by new instances of the frame (unless overridden by the user). A frame can have an "is-a" slot which indicates a "parent" frame. A "child" frame inherits all of the slots and corresponding default values of its parent frame, although additional slots can also be defined for a "child" frame.

In the context of equipment management systems, frames include:

1. A type of equipment item, such as a bulldozer or a pickup truck

2. A specific brand of equipment item which inherits the slot values of the type of frame as defaults, and has different default values

3. A specific component type, such as a transmission or pickup truck transmission, which can be a slot in an equipment frame

4. A specific brand of component type which can inherit the default slot values of the component type frame

5. A description of a major repair which will occur one or more times during an item's life. Examples are engine and transmission overhauls. The slots for this frame will probably have no defaults, but will simply define the type of data required to describe a major repair,

Figure 3 shows a simplified example of frames with a limited number of slots, as they would be applied to a fleet management system. The arrows marked "isa" indicate that the frame "pointed to" inherits the slots (and any values) of the frame "pointed from." A slot value can be a number, text, an array of numbers, or another frame. For example, the slot value of Engine in Frame P7865 (the truck's license number) is the engine with serial number M87639. In order to analyze all pickup trucks, a computer program using an efficiently implemented frame structure would seek all frames which are pickup trucks.

Slots for Fleet Management Decisions

A frame-based approach to any problem must differentiate between slot defaults for a frame and how to calculate them, and slot values for an instance of the frame. The slot default for the frame may be a complicated procedure which accesses data from some data base and either: (1) using one or more data bases, calculates a default value for an instance of the frame, (2) if the proper or adequate data exists in the data bases relevant to the frame instance, calculates a specific slot value for the frame instance, or (3) gives the user the option of entering information which may or may not be used in conjunction with data bases to calculate the slot value. For instance, one slot is "expected annual usage of an item." The fleet manager can estimate this value or derive it from past history. If deriving the value from past history, the fleet manager retains the option of substituting an alternate value, if the manager's judgment or expectation of the future differs from past history.

The rest of this section discusses necessary slots for equipment and component frames relevant to the fleet management decisions, slot defaults for frames, and slot defaults and values for frame instances. Sources of data include existing repair records, manufacturers' recommendations, data tabulated by trade and professional organizations, and the judgment of the equipment fleet managers. This section also discusses slots requiring data which are not likely to be included in, or cannot be derived from, data in an equipment fleet management system.

Slots Related to Productivity and Usage Units

DEH DBMS should include the following slots:

1. Units of production—These are usually specified for the frame, or group of items. However, the units may be specific to a single item if the type of work for that item differs from that of the rest of the members in the group.

2. Meter unit—Most equipment management systems will track meter hours, miles, or kilometers as a measure of usage. A measure of units of production may need to be introduced.

3. Expected units of production per year—This may be estimated by the user, or derived from past data either for the frame or for an instance. This may be a table with a value for each of the next several years. An annual frame default value or table will be specified, which may be revised for instances of

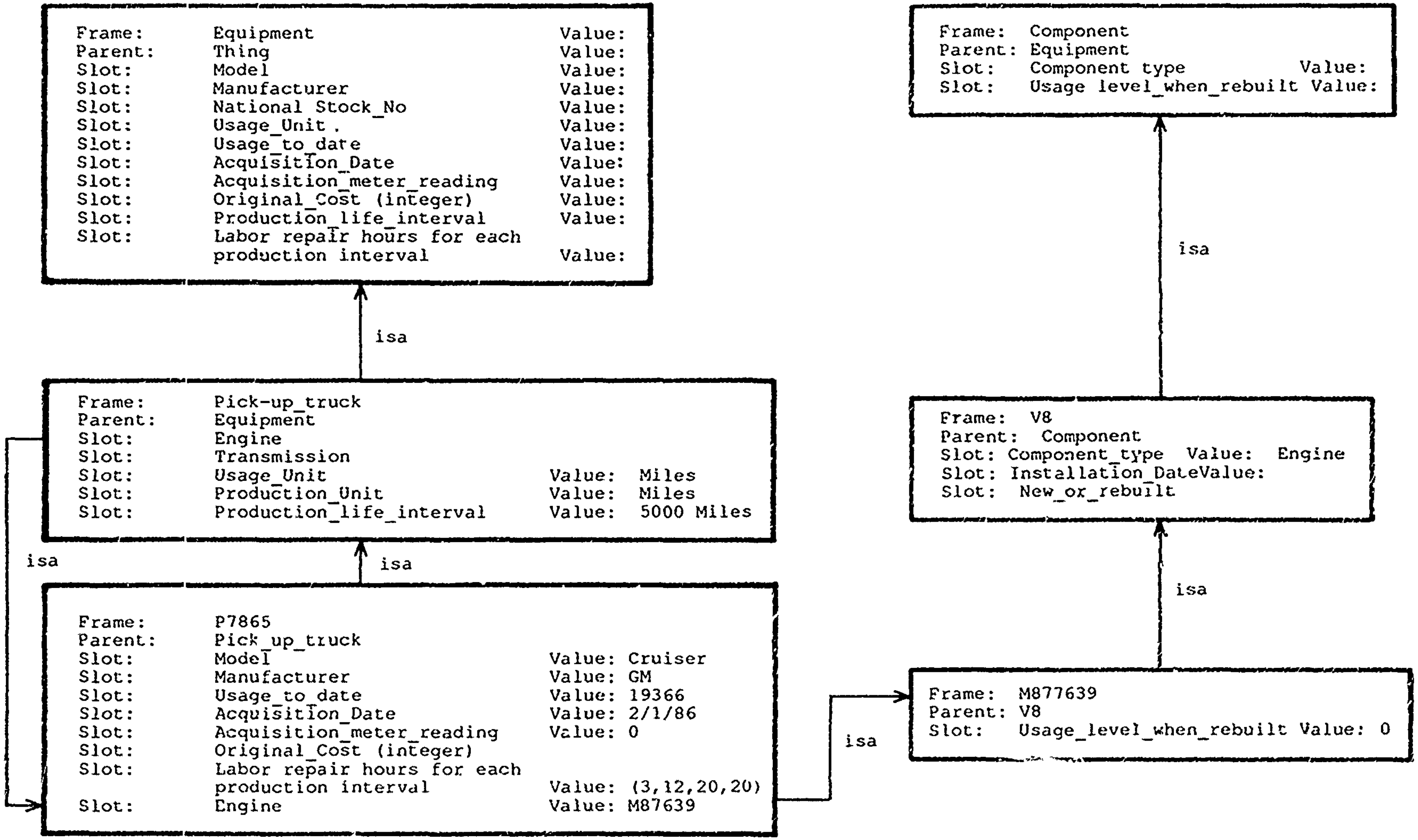

Figure 3. Example of frames.

the item. It may also be estimated from the next two slots. Ultimately, this is the measure of usage of greatest interest. For a frame instance, this value may depend on the alternative being considered.

4. Units of production/meter unit—This value equals one if "units of production" equals the meter unit. This may also be specified as a function of units on meter, age, age of engine, or some other component, rather than a single value. It may be specified for a specific piece of equipment, or frame instance, if the item is devoted to some task that changes its productivity from other similar items. If production units and meter units have been saved in a data base, this data item could be derived for the frame (the equipment group as a whole) or for individual instances.

This measure captures the phenomenon that operators sometimes report that an equipment's ability to perform decreases with age. Comparing the estimates of productivity of new, old, and rebuilt equipment will influence economic analysis.

5. Expected meter units per year—Estimates of any two of this slot and units of production/meter unit, implies an estimate of expected units of production per year. If the units of production and meter and unit are the same, then this and the previous slot are identical.

6. Fuel usage per production unit or per meter unit—This may be estimated from existing data or manufacturer's information. This item is relevant only for certain equipment items or certain components.

7. Operator hours per production unit or meter unit or per day—This is generally relevant to heavy equipment, but not to a craftsperson's tool truck. Often this can be calculated from units of production per meter unit.

8. Estimated salvage value in each successive year from the present—This information is generally derived from published surveys of used equipment prices, combined with management's judgment. Although calculated for each type of equipment, or frame, salvage value is revised for an individual piece if it has had especially heavy or light use, or if it has undergone a major overhaul. Assuming all cost comparisons are made after adjustment to constant dollars, salvage values can be calculated based on:

- a percentage of the equipment's cost when new
- the percentage of the current price of a replacement equivalent to the replaced item when new
- current market prices for the identical or comparable equipment at each age.

Of course, the user can explicitly update the information each year, and make modifications as necessary to reflect the condition of specific items.

9. Production unit lifetime intervals for the type of equipment or system —These intervals are used to aggregate actual and predicted repair and maintenance costs for the item. The unit and size, such as miles or hours, should be appropriate to the item. For example, light trucks could be grouped as 0-5000 miles or 5000-10000 miles, and bulldozers could be grouped as 0-100 hours, 100-200 hours. Conceivably, the lifetime intervals could be expressed as the range of some function, likely linear, of the age and some production unit. Specific subsystems or components of a larger item may have units of production measured differently from the larger item.

Slots Related to Maintenance and Repair

DEH DBMS should include the following frames:

1. Cost of the item when new, and date when new—All repair costs adjusted for current price levels will be normalized by this value, which will also be adjusted to current price levels.

2. List of major repairs periodically made to the item or which should be tracked—This is a list of instances of the frame for major repair, associated with the frame for the equipment item. The slots in the major repair frame are:

- System or component or repair code—This co .e depends on the conventions of the underlying equipment maintenance management history.
- Description—such as repair, replace, or rebuild.
- Units of frequency—This can be expressed as time, units of production, or some function of the two. A useful function could be an increment of calendar time, miles or hours, and/or units of production, whichever comes first.
- Expected frequency—This is an estimate of a pessimistic, most likely, and optimistic frequency of occurrence, expressed in units of frequency. These estimates are based on either manufacturers' or published data, professional judgment, or historical records. For a given equipment type, the computer can analyze repair records to derive an estimate of the average frequency between occurrences of any major repair. The computer can indicate this estimate and some measure of its accuracy, such as its variance. The more history which exists in the records, the more accurate the estimate. (If many installations coordinated their efforts, an Army-wide data base could be used.) The user can then decide whether to accept the estimate or insert an alternate value based on judgment or manufacturer's information. An instance of this repair within an instance of some equipment item frame could have user designated frequency estimates, to reflect users' judgment of the effect of the types of tasks assigned to the equipment item. The estimates made depend on how the frames are defined. For example, estimates can be derived for all small trucks, pickup trucks, and specific models of pickup trucks.
- Expected usage until next occurrence—This is given as a single value, or as the three estimates of a pessimistic, most likely, and optimistic time until the next occurrence. This slot, although defined in the frame, is actually completed for each instance of the frame. Its default values are calculated from the last occurrence and the expected frequency. The typical use, an inspection, or some test (such as compression or oil sample) of the item is a basis for a user to modify the default prior to some analysis.
- Expected labor hours required—This is initially derived from industry and/or Army standards, and is modified over time according to accumulated data. The computer can estimate the values from historical records, which the user can modify if desired.
- Parts list or parts cost—For parts cost, the date associated with the cost must be retained.
- Date, units of production, and meter units when the repair was last performed.

- Labor hours and parts list or costs for PM service to the item

- List of components or systems for which repairs should be individually tracked—This is a list of component frames. Each such component has the following slots:

a. System or component name—This can be unique to the whole equipment item, or to the component of a specific manufacturer, such as a certain transmission in several heavy equipment items. Or, original and rebuilt items may be differentiated.

b. List of major repairs associated with this system—This is a list of repair frames.

Repairs to the system not designated as major repairs use the following three slots:

a Labor hours or cost of repair for the repair to be designated as system-specific. Repairs falling below this threshold are not considered system-specific repairs.

b. Parts cost and labor hours or total repair cost during each lifetime interval. The first two rather than the third are preferable, but the previously maintained repair history may force use of the third.

As a general rule, an equipment item cannot be designated as having a specific component type, unless that component type's repairs are individually tracked for that item.

When performing an analysis, all cost data pertaining to repairs are adjusted to current price levels, and are then divided by the original purchase price of the item, which is also adjusted to current price levels. The average of these values for all equipment items which are instances of the frame are the default value for the frame.

3. For repairs which are not system-specific, actual parts cost and labor hours or total cost during each lifetime interval—This data is derived from historical records and then used in a manner analogous to the system-specific, nonmajor repairs.

At certain intervals, possibly annually, a routine should be triggered to review the current estimates of many of the above slots.

When accumulating data for these slots, parts and labor related to accidents and abuse should probably not be included, but should instead be considered as a separate cost component assessed against a class of items on a per production unit basis.

LAD Costs-Related Slots

The following slots relate to types of equipment or systems, rather than to individual equipment items. If these LAD cost slots are related to systems, then the data for systems-related breakdowns must be subtracted from the breakdowns of equipment whose components they are. These items should be available from repair order history:

1. Number of field breakdowns per production unit—calculated for each lifetime interval.

2. Number of shop labor hours due to field breakdowns per production unit—calculated for each lifetime interval.

3. Number of hours of downtime due to field breakdowns per production unit—calculated for each lifetime interval. Hours down can be measured as working hours for either the repair shop or the department, although these might be equivalent in some organizations. Department hours are more relevant to LAD costs. Although shop labor hours certainly correspond to the collective nature of the failures, the actual number of hours may depend on shop staffing and the efficiency of the procurement system. Thus, if an organization's ratio of downtime caused by breakdowns to shop time caused by breakdowns is expected to change, a ratio should be developed to convert the historical data for shop time due to breakdowns, to projected downtime due to breakdowns.

Data from Equipment Management Systems To Support Fleet Management

Full utilization of the above description of slots requires a good history of maintenance and repair records. The most important data from a fleet management system include a repair order with:

1. Equipment and, if appropriate, component identifier (ID)

2. System code

3. Labor hours and/or labor cost of the repair

4. Parts cost

5. Description of work (rebuild, replace, overhaul, repair, adjust, exchange, PM, etc.)

6. Usage on equipment at time of repair

7. Date of repair

8. Reason for repair (breakdown, operator report, abuse, neglect, accident, etc.)

9. Hours of downtime

For individual pieces of equipment and selected components, the system should include:

1. Equipment identifying number

2. Expected units of production/year (considering the time the item is expected to spend in repair)

3. Meter (miles or hours)

4. Units of production/meter unit (if different from the values for system or type)

5. Current major components:

   • New or rebuilt

   • Usage when installed

   • Date installed.

However, many installations have incomplete repair history records. Therefore, two or three levels of data compliance shall be defined. The lower levels will require less detailed historical records. For example, a very low level of compliance might occur if the repair history contains only:

1. Equipment ID

2. Date of repair

3. Parts cost

4. Labor cost.

If the repaired component is excluded, analyses might have to be performed for equipment items as a whole, possibly preventing a proper consideration of downtime in any analyses. An even lower level of compliance might not differentiate repair parts and labor costs.

Deriving Cumulative Cost Curves for Economic Analysis

The discussion of the various frame slots indicated how cumulative cost curves can be derived. In any alternative analysis, cumulative cost curves must be obtained to predict future costs. A total cumulative cost curve is the sum of the cumulative cost curves for operating expenses, miscellaneous repairs, specific major repairs, and specific and miscellaneous repairs for selected components. Figure 1 in Chapter 2 illustrated a cumulative cost curve. Under the scenario of this paper, such a cumulative cost curve would be the sum of cumulative cost curves for depreciation, operating costs and various component and nonspecific repair costs. Each equipment type has a unique combination of these curves. The dimension of the horizontal axis for cumulative cost curves is a function of age, meter, and/or production units. Projected usage for each equipment item should be calculated annually.

Analysis of any alternative, whether an incumbent, defender, or a repair or replace decision, must begin by identifying the type of equipment (i.e., an instance of a frame). The challenger's equipment type is usually the same as that of an incumbent's frame. For purchased new, rebuilt, or used equipment, the initial cost of the alternative, in project repair costs, and its productivity are specified. Users can then revise any of the alternative's parameters.

5 SOFTWARE ENVIRONMENT TO IMPLEMENT FLEET MANAGEMENT DECISIONS

From the user's perspective, decision support software for the types of decisions addressed in this report must:

1. Automatically incorporate technical knowledge of economic analysis

2. Guide users through the various steps for correctly defining groups of equipment, instances of equipment, and alternatives

3. Accept data in a variety of detail and quality from various equipment management systems, each of which have unique data reporting habits, and select appropriate forecasting and statistical validation techniques

4. Present key elements of decision-making logic to users

5. Produce output reports that can be easily interpreted.

The quality and detail of the incoming data depends on the equipment management system's capabilities and on the organization's record keeping habits. Implementing the decision support software as an independently operating software package requires data transfer from an equipment management system to the decision support system's own frame and slot data structures. Therefore, the software should be capable of recognizing and describing the content of the incoming data. The software could then select appropriate techniques to forecast future costs. Alternatively, the decision support software can be developed with a customizable interface, allowing it to be integrated into an equipment management system.

The decision support software requires an environment which allows revision of the underlying logic (i.e., rules and procedures for completing frames, forecasting cost curves, and recommending actions) both during development and after implementation. Rules which seemed sound during development might be found by users to be inappropriate or incomplete. An expert system shell allows corresponding revisions with minimal programming effort.

To more easily effect use of data from various equipment management systems, which will likely reside on microcomputers or networks, the expert system shell should either directly access several common data base microcomputer formats, or communicate with procedures in some language which can.

Several commercial expert system environments are now being reviewed, all of which either communicate with or are an extension of the C programming language. Available libraries allow C to communicate with almost any data base format.

6 SUMMARY

The recent introduction of computerized equipment management systems at several Directorates of Engineering and Housing (DEHs) allows the collection of extensive data on vehicle operating and maintenance histories. When appropriately processed, this information can help fleet management decision making. Fleet management decisions are based on the projected future owning and operating costs of current ("incumbent") and proposed alternative ("challenger") equipment items in a fleet. Such projections are derived from records which include:

1. Operating costs
2. Preventive maintenance costs
3. Repair costs
4. Capital deterioration
5. Taxes and insurance
6. Lack of Availability and Downtime costs.

A calculation of these costs, in constant dollars, can be used to estimate the Equivalent Uniform Annual Costs (EUAC), or cost of any piece of equipment budgeted into yearly installments. Costs of incumbent and challenger equipment can be compared to decide whether to repair, rebuild, or replace an incumbent piece of equipment. A similar comparison between the costs of owned and leased equipment can help determine which alternative is more cost effective.

Equipment items that operate from an equipment pool often share workloads. To account for the interdependence of many items in a pool, vehicle costs and usage must be consistently recorded. This tracking can be used to create economic projections over several years' time that cover group as well as individual costs, and may allow DEHs to charge DEH shops and projects directly for the recorded use of equipment fleets.

A "frame-based" programming approach can be useful to structure data for equipment maintenance and management computer programs. A "frame" (category) contains "slots" (entries). Slots may contain logical rules, procedures, or can themselves be frames, containing slots which are either data fields, or other frames. In this way, maintenance and management information (vehicle data, maintenance records, parts inventories, etc.) can be organized hierarchically and cross indexed. DEH fleet managers should begin with identical frame-based structures and later tailor the systems to individual needs, to similarly organize and pool information of common interest.

Decision support software to perform these tasks must accept standard format data generated by the data base management systems currently used by DEH fleet managers. The software must be user friendly, and have a report generating capability that produces logically clear and easily interpreted output.

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